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Distribution of Benthic Invertebrates along a Disturbed Section of the La Trobe River, Victoria: an Analysis Based on Numerical Classification

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Abstract

The benthic invertebrates of the banks and main channel at 10 sites along 100 km of the lower reach of the La Trobe River, which flows entirely through agricultural and industrial areas, were quantitatively sampled every two months between May 1979 and March 1981; 23 chemical variables were measured concurrently. In all, 337 taxa were collected. Normal and inverse classifications of the faunal data with two similarity indices (Czekanowski, Canberra Metric) indicated that the uppermost two sites (upstream of the industrial areas) with a rich fauna were clearly distinct from the more depauperate downstream sites; these latter sites could be divided into two groups (main channel samples) or four groups (bank samples). In both habitats, eight groups of common (>0·5% of total numbers) taxa were evident: in each habitat, there were one or two groups of resistant taxa abundant at all sites (mostly Chironomidae), one or two groups of opportunistic taxa common at disturbed sites only (Caenidae, Corbiculidae, Ecnomidae, Chironomidae), and two groups of sensitive taxa that were most abundant at the two uppermost sites (Leptophlebiidae, Baetidae, Ecnomidae, Elmidae, Helodidae, Chironomidae, Ceratopogonidae, Hydracarina). Oligochaeta were abundant at all sites and as a group were considered resistant. Multiple discriminant analysis of the previously established site groups with 17 of the chemical variables indicated that high values for conductivity distinguished the most downstream site groups, which had the poorest fauna; the effect of this factor on the fauna was apparently indirect. The analysis also indicated that a decrease in suspended solids at site groups on an impounded section and an increase in nutrients at a site immediately downstream of the input of treated sewage were associated with changes in the fauna. The release of heated water (<25°C) from a power station at one of the sites on the impounded section had little effect on the fauna.

Introduction

Much development has occurred in the lowland catchment of the La Trobe River during this century and the river in this region now flows entirely through agricultural and industrial areas. The major industrial activity is the generation of electricity from brown coal by the State Electricity Commission of Victoria (SECV). The SECV discharges heated cooling water from power stations and releases saline effluent to the lower reach of the La Trobe River. In this paper, the effects of these disturbances, and others, on the benthic invertebrates in this reach of the river have been determined by analysing the spatial patterns of the fauna. According to Green (1979), this is the best solution when no data on conditions before disturbance are available. Green recommends numerical classification of the fauna for such an analysis, followed by discriminant analysis to relate environmental features to the faunal groups.

Few studies have been made in temperate (southern) Australia of the distribution of macroinvertebrates of disturbed (mostly lowland) rivers, and even fewer using numerical classification of the fauna. However, the effects of dam construction on the benthic fauna

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of rivers have been studied (Blyth 1980), as have the effects of organic pollution (Jolly and Chapman 1966; Campbell 1978; Arthington *et al.* 1982) and heavy metal pollution (Thorp and Lake 1973; Norris *et al.* 1982). In addition, some information on benthic invertebrates is already available for the lower reach of the La Trobe River (Blyth 1979) and for the River Murray (Walker and Hillman 1977), which is also subject to various disturbances.

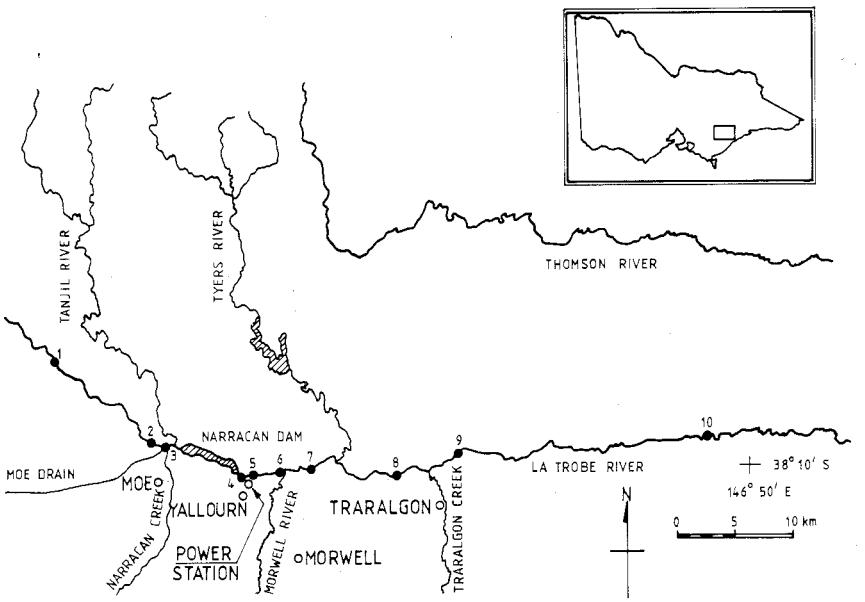

Fig. 1. The study area, showing the ten sampling sites (1–10).

Study Area

Ten sampling sites (Fig. 1) were chosen along about 100 km of the lowland section of the river (altitude <150 m and slope 0·6 m km^{-1}). Generally, the river here is 15–20 m wide and <1 m deep; the substratum is medium to coarse sand in the main channel and fine sand to silt along the bank. Sites 1, 2 and 3 (Fig. 1) are upstream of the industrial areas and at these sites grazing land borders the river. Site 3 is about 100 m downstream of the entry of the Moe Drain, which carries sewage from a nearby treatment works. Site 4 is immediately downstream of the Narracan Dam and is substantially different from the other sites in that the banks and substratum of the river are rocky and the main channel is 2–3 m deep. The dam provides water for various SECV power stations. The Yallourn power station weir is 2·7 km downstream of the dam, resulting in low flow at site 4. Site 5 is about 100 m downstream of this weir and of the entry point of heated water from the cooling towers of the Yallourn power station. About 250 m downstream of the entry of the heated water there is another weir (the L5 weir), and site 5, like site 4, generally has low flow. The only emergent vegetation at any site [a stand of *Phragmites australis* (Cav.) Trin. ex Steud.] occurs along the banks at this site. Site 6 is immediately upstream of the entry of the Morwell River and about 1 km downstream of the entry of the outfall of the Blue Lagoon, which principally discharges saline water resulting from SECV operations. Such saline wastes (as well as some sewage) are also discharged into the Morwell

River. There are several logs in the main channel at site 6, which obstruct flow. Sites 7–10 are all in open grazing country. Between sites 7 and 8, the Australian Paper Manufacturers (APM) pulpmill discharges some waste. There are no direct discharges of industrial waste to the river downstream of the APM pulpmill, although some discharges may enter via various tributaries. The main channel at site 10 is 2 m deep and patches of clay are present in the substratum.

In addition to the various disturbances outlined above, there are undoubtedly diffuse discharges from the agricultural land that borders most sites (except 4 and 5). Thus, sites 1 and 2 cannot be regarded as undisturbed, even though they are upstream of the industrial development, but could be considered as subject to the fewest obvious disturbances.

Annual rainfall in the lowlands of the La Trobe River is 800–1000 mm, but is considerably higher (up to 1800 mm) in the upper catchment (Anon. 1976*a*). Annual discharges at site 10 during the study were only 50–70% of the mean annual discharge at site 10 (943×10^6 m^3; Chessman 1982).

Methods

At each site, 30 samples, 15 from the main channel of the river and 15 within 1 m of the bank, were collected on 12 occasions, every two months between May 1979 and March 1981. All samples were collected with an airlift sampler, described by Norris (1980). This device worked best in water >0·5 m deep (as at sites in the present study) and sampled an area of 0·02 m^2 to a depth of 5–10 cm; a catching net of 150-μm mesh was attached. Three blasts of air were always used to disturb the substratum, when taking a sample. A series of 30 cm long core samples at site 1 in January 1982 revealed no specimens deeper than 5 cm in the sediment at the bank; in the main channel, fauna penetrated to 30 cm, although 60–70% of the fauna was within 10 cm of the surface. Thus, the airlift sampler probably did not collect all the specimens within its sampling area. However, it did provide comparable samples and a similar apparatus operated at similar air flows on sand by Drake and Elliott (1982) generally sampled surface fauna (down to 3 cm) quantitatively.

The samples were preserved in the field in 5% (v/v) formalin. In the laboratory, the invertebrates (and other organic matter) were floated from the accompanying sand and silt in a saturated solution of calcium chloride and preserved in 70% (v/v) ethanol. The specimens were subsequently sorted, identified and counted under low magnification. Occasionally, when a sample contained large numbers of specimens, a subsample of one-tenth was taken by dispersing the unsorted sample within a watertight box, the bottom of which was divided into 100 compartments or cells. Tests showed that the fauna was randomly distributed among these cells. On all occasions, the subsample of 10 cells contained at least 100 specimens and, thus, the standard error of the estimate of actual numbers in the total sample was <10%. Specimens were identified, generally to species, using published keys and a voucher system set up by the Biological Survey Department of the Museum of Victoria. Specimens of all taxa were deposited in this museum.

On each sampling occasion, water velocity was measured with an Ott meter within 1 m of the bank and in the main channel at each site. Measurements were taken at 0·2 and 0·8 of the depth and averaged to give mean velocity, except at sites 4 and 10 where surface (approximately 50 cm below the surface) readings only could be taken in the main channel because it was too deep. Such measurements indicated only the general conditions of flow at each site. Water velocity near the bottom is probably of more importance for the benthos, but different apparatus would have been required to measure it effectively.

Sediment samples were also collected from the two habitats except from the main channel at site 4. To take a sample, a scoop was drawn over the surface of the sediment to a depth of about 5 cm. In the laboratory, each sample was split in half. The organic content of one half was measured (as percentage carbon) by burning the sediment in a Leco induction furnace at 1300°C. Mean particle size of the other half of the sample was estimated by weighing the amount of (dry) sediment trapped on a series of sieves of various mesh sizes.

At each site, water quality was determined by measuring 23 variables commonly used to assess industrial water pollution. Measurements were made in the same months as each set of faunal samples was taken. Standard methods (Anon. 1976*b*) were used for all variables.

The arithmetic mean number of individuals per sample ($\bar{x}$) and the 95% confidence limits (95% c.l.) were calculated for the 15 samples from each habitat at each site. The confidence limits were calculated after transforming the original counts (x) to $\log_{10}(x+1)$, as recommended by Elliott (1977) when dealing with small numbers of samples (<30), where the variance (s^2) is greater than the mean ($\bar{x}$).

Table 1. Water
All concentrations

Site	pH	O_2	Temp. (°C)	TDS[A]	SS[B]	Turbidity (NTU)	K_{20} (mS m^{-1})	C.O.D.	B.O.D.	Colour (Pt)	NO_2-N
1 Mean	6·8	8·7	13·8	69	23	9·6	7·6	21·1	1·0	62	0·004
Max.	7·1	11·0	20·6	90	50	24·0	9·7	29·2	1·8	90	0·007
Min.	6·0	7·6	8·0	55	6	2·5	6·1	15·0	0·3	45	0·001
2 Mean	6·7	9·1	13·7	81	25	12·5	9·2	19·0	0·9	51	0·005
Max.	7·2	11·6	20·6	110	50	25·0	13·5	28·8	1·6	70	0·020
Min.	5·8	7·8	8·0	70	9	3·3	7·2	3·2	0·1	35	0·001
3 Mean	6·8	7·9	16·7	157	34	26·0	21·9	22·6	1·9	38	0·010
Max.	7·3	9·8	21·9	200	60	43·0	28·2	30·2	2·6	45	0·016
Min.	6·4	5·7	10·5	110	17	11·0	14·2	10·1	0·5	35	0·006
4 Mean	7·0	9·1	15·9	108	23	21·0	13·9	19·1	1·7	44	0·006
Max.	7·6	11·5	22·5	150	90	67·0	19·7	26·8	2·3	55	0·015
Min.	6·5	7·2	9·0	85	8	8·0	10·3	16·0	0·8	35	0·002
5 Mean	7·1	8·8	20·0	111	20	19·8	14·6	19·9	2·0	42	0·005
Max.	7·5	11·6	25·4	150	45	51·0	19·5	26·9	4·0	55	0·014
Min.	6·4	7·2	15·5	83	9	5·2	10·9	11·0	0·1	30	0·001
6 Mean	7·2	8·8	19·6	173	20	20·0	24·8	19·1	1·5	44	0·008
Max.	8·1	11·4	27·0	280	40	46·0	42·0	29·4	2·0	60	0·031
Min.	6·6	7·1	12·5	110	10	9·8	14·2	15·0	0·7	30	0·000
7 Mean	7·2	8·9	18·0	221	48	33·0	32·7	21·1	2·1	44	0·006
Max.	7·6	11·8	23·0	350	185	118·0	50·0	49·1	7·9	60	0·015
Min.	6·4	7·2	11·2	140	14	12·0	23·0	2·6	0·7	35	0·001
8 Mean	7·2	8·8	17·5	242	38	27·3	34·4	25·5	2·1	47	0·006
Max.	7·9	10·8	23·5	445	90	65·0	62·0	33·8	5·5	70	0·016
Min.	6·8	6·8	11·3	140	16	11·0	21·0	16·2	0·7	35	0·001
9 Mean	7·2	8·5	17·0	247	46	36·1	31·1	25·3	2·0	46	0·006
Max.	7·7	10·5	23·5	440	135	76·0	60·0	33·5	3·2	62	0·014
Min.	6·7	6·9	11·0	155	18	14·0	4·9	18·3	0·4	35	0·002
10 Mean	7·3	8·6	17·2	249	83	42·0	34·9	23·3	2·3	46	0·005
Max.	8·3	10·0	23·5	410	190	89·0	60·0	33·6	4·1	60	0·014
Min.	6·7	7·3	10·5	155	43	16·0	21·3	6·8	0·2	35	0·001

[A] TDS, total dissolved solids. [B] SS, suspended solids. [C] TKN, total Kjeldahl nitrogen. [D] FRP, filterable

To group the sites on the basis of the composition and abundance of their fauna (normal classification), two similarity indices were calculated: Czekanowski's index (Hellawell 1978) and the Canberra Metric index (Clifford and Stephenson 1975). These two indices were also used to group taxa by their distribution and abundance among sites (inverse classification). For this classification, only taxa whose abundances were >0·5% of the total population were used. For both classifications, Czekanowski's index was used only after transforming all abundances to $\log_{10}(x+1)$ to lessen the influence of particularly abundant taxa on the index; the formulation of the Canberra Metric index specifically prevents such an influence. Both these indices (or slightly different versions of them) are fairly commonly used in ecological studies, according to Clifford and Stephenson (1975). Hierarchical grouping of the sites or the taxa was performed by program BMDP1M (Dixon 1981) using average linkage clustering, that is by calculating the average similarity values.

The water quality data were subjected to stepwise multiple discriminant analysis (BMDP7M with pre-assigned options; Dixon 1981). This analysis determines the extent to which the groups of sites (based on faunal similarity) can be distinguished by using the chemical data. If the groups are well

distinguished, the discriminating chemical variables can be considered as closely associated with changes in the fauna.

Principal components analysis was also used to analyse the chemical data (BMDP4M with pre-assigned options; Dixon 1981). Basically, this technique reduces the 23 chemical variables to a smaller number of composite factors that account for a large proportion of the variability between sites.

quality data
are given in mg l^{-1}

NO_3-N	NH_4-N	TKN[C]	FRP[D]	TP[E]	HCO_3^-	SO_4^{2-}	Cl^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
0·381	0·10	0·44	0·006	0·106	14·0	2·9	22·0	9·6	1·5	2·6	2·1
1·206	0·28	1·45	0·013	0·790	25·0	11·0	36·4	12·5	1·7	2·0	2·6
0·107	0·01	0·14	0·000	0·005	8·0	1·0	11·8	7·5	1·3	1·6	1·4
0·350	0·12	0·49	0·011	0·100	12·5	3·6	28·1	12·3	1·6	3·5	2·7
0·810	0·29	1·37	0·028	0·780	25·5	7·0	53·0	19·0	1·9	7·7	4·8
0·056	0·01	0·01	0·004	0·010	7·4	1·0	14·8	9·3	1·3	2·4	1·7
0·537	0·33	1·12	0·150	0·198	27·0	6·2	56·4	29·3	2·8	5·4	5·4
0·776	0·66	1·58	0·321	0·383	36·0	10·0	70·0	38·0	3·9	6·1	6·9
0·144	0·14	0·65	0·060	0·148	17·0	2·0	34·0	21·0	2·4	4·1	3·3
0·048	0·13	0·86	0·030	0·118	17·0	5·5	38·9	18·5	1·8	4·2	4·0
1·900	0·38	2·11	0·083	0·335	23·0	14·0	67·0	22·9	2·8	7·2	5·2
0·027	0·01	0·20	0·000	0·013	11·0	1·0	22·9	13·0	1·2	0·7	2·6
0·150	0·15	0·79	0·030	0·096	18·0	6·6	39·4	18·9	1·8	4·7	4·2
1·786	0·34	2·10	0·109	0·253	31·0	22·0	75·0	27·0	2·8	8·8	5·4
0·008	0·01	0·21	0·010	0·013	10·0	1·7	18·6	13·7	1·4	3·4	3·0
0·460	0·14	0·72	0·022	0·107	21·0	45·0	47·6	32·3	2·2	8·3	10·6
1·770	0·41	1·97	0·069	0·286	36·0	115·0	107·0	53·7	3·1	15·0	17·1
0·009	0·01	0·12	0·000	0·011	11·0	10·0	26·5	16·2	1·8	1·9	6·9
0·430	0·12	0·67	0·025	0·167	37·0	41·5	62·7	47·7	3·3	10·9	8·1
1·990	0·28	1·87	0·056	0·960	84·0	100·0	78·0	81·0	5·2	17·0	19·0
0·012	0·01	0·15	0·000	0·025	13·0	1·0	43·3	28·0	2·2	5·8	5·0
0·480	0·16	0·77	0·026	0·118	33·0	46·8	66·2	53·1	3·1	16·2	6·5
1·550	0·41	1·92	0·046	0·339	61·0	141·0	89·0	112·0	4·6	40·0	7·9
0·063	0·01	0·27	0·009	0·033	16·0	10·0	51·5	30·0	2·0	5·8	5·1
0·459	0·14	0·80	0·026	0·145	37·0	51·3	70·2	47·9	3·1	17·0	6·7
1·450	0·25	2·71	0·055	0·271	60·0	128·0	128·0	89·0	4·5	43·0	7·9
0·068	0·03	0·31	0·010	0·020	15·0	19·0	49·0	28·3	2·0	5·8	5·1
0·485	0·20	0·68	0·023	0·110	36·0	47·8	71·0	48·4	3·3	15·7	7·3
1·710	0·65	1·16	0·047	0·353	58·0	107·0	98·0	89·0	4·8	35·0	8·7
0·032	0·01	0·18	0·005	0·024	14·0	14·0	52·0	29·3	2·2	5·8	5·4

reactive phosphorus. [E]TP, total phosphorus.

Results

Water Velocity

Water velocities ranged from 7 to 97 cm s^{-1} in the main channel, with a mean for all sites of 48 cm s^{-1}; at the bank they ranged from 0 to 44 cm s^{-1}, with a mean of 10 cm s^{-1}. Significant differences between sites could not be shown for velocities at the bank (one-way ANOVA $F_{9,108} = 1 \cdot 13$, $P > 0 \cdot 05$) but could be shown for those in the main channel ($F_{9,108} = 6 \cdot 28$, $P < 0 \cdot 001$). As a result of the impoundment of the river, sites 4 and 5 had mean velocities in the main channel (26–28 cm s^{-1}) that were about half those of the other sites (54 cm s^{-1}). A Student–Newman–Keuls test (SNK test, Sokal and Rohlf 1969) confirmed that mean velocities at sites 4 and 5 were significantly ($P < 0 \cdot 05$) lower than at other sites.

Sediment Characteristics

Mean particle size varied significantly between sites: $F_{8,35} = 17 \cdot 58$, $P < 0 \cdot 001$ for the main channel samples and $F_{9,42} = 3 \cdot 05$, $P < 0 \cdot 001$ for bank samples; and was consistently smaller at the bank (0·1–1·6 mm) than in the main channel (0·3–2·5 mm). SNK tests showed that in both habitats site 1 had significantly ($P < 0 \cdot 05$) coarser sediment than the other sites.

Mean carbon content of the sediment did not vary significantly between sampling sites ($F_{8,74} = 1 \cdot 78$, $P > 0 \cdot 05$, for main channel samples and $F_{9,80} = 1 \cdot 69$, $P > 0 \cdot 05$, for bank samples, after application of the arcsine transformation) but was always higher at the bank (0·6–2·4% dry weight) than in the main channel (0·3–0·9%) for each pair of habitats. Because samples were not preserved, e.g. by freezing, in order to stop biological activity, it is possible that their carbon contents were somewhat underestimated. However, the values are probably a reliable index of organic content, as they were higher at the banks where velocities were lower and where organic particles might be expected to be deposited.

Water Quality

The means and ranges of the 23 chemical variables are given in Table 1. Significant differences between sites (one-way ANOVA, $P < 0 \cdot 05$) were shown by the values for all variables except O_2, COD, NO_2-N, NO_3-N, NH_4-N, TKN and TP. Data for six variables (COD, BOD, colour, NO_2-N, NO_3-N, NH_4-N) were missing, so these variables were excluded from the multivariate analyses presented below.

Table 2. Mean number of taxa ($\bar{s}$) and overall mean density (N, No. of individuals per square metre)

Variable	Value of variable at site:									
	1	2	3	4	5	6	7	8	9	10
					Main channel					
$\bar{s}$	55	28	28	24	20	28	13	12	10	22
$10^{-3} \times N$	12·6	4·3	7·5	3·1	4·6	8·6	2·1	1·9	0·6	4·6
					Bank					
$\bar{s}$	79	72	36	27	22	25	21	23	26	36
$10^{-3} \times N$	17·8	15·1	8·6	5·6	3·1	3·5	3·3	3·8	7·9	14·1

Basic Features of the Fauna

Altogether 337 taxa were collected during the study. A systematic list of these taxa and their abundances at each site are given by Marchant *et al.* (1984). On each sampling occasion, collections of the fauna at a site appeared comprehensive as 50–80% of the total number of taxa caught occurred in the first five samples and more than 90% in the first 10 samples.

The 95% c.l.s for the number of individuals per sample at a site were generally 30–50% of the mean density on any visit. This degree of variability was not great enough to obscure spatial and temporal differences in density (see below) and was similar to the level of error (40%) that Elliott (1977) considered reasonable for bottom samples. The additional variability introduced by occasional subsampling added about 4% to the confidence limits and was thus negligible; this was determined by summing the square of the standard error from the 95% c.l.s with the square of the standard error due to subsampling and converting the squared total standard error back to 95% c.l.s.

The variations in mean number of taxa and overall mean density between sites are indicated in Table 2. *t*-Tests (for unequal variances, Sokal and Rohlf 1969) showed that

Table 3. *F*-ratios and levels of significance for spatial and temporal variation from two-way ANOVAs of number of taxa (s) or mean density ($\bar{x}$)

All $\bar{x}$ values were transformed to $\log_{10}(x+1)$. n.s., not significant; *$P<0{\cdot}05$; **$P<0{\cdot}01$; ***$P<0{\cdot}001$

Sites	Variable	*F*-ratio for: spatial variation	*F*-ratio for: temporal variation
		Main channel	
1 and 2	s	18·3**	2·9*
	$\bar{x}$	23·7***	3·8*
3–10	s	7·8***	2·4*
	$\bar{x}$	7·7***	2·4*
		Bank	
1 and 2	s	1·1 n.s.	1·2 n.s.
	$\bar{x}$	0·2 n.s.	3·1*
3–10	s	6·7***	5·5***
	$\bar{x}$	3·3**	2·0*

Table 4. Percentage abundance of major invertebrate groups

Major invertebrate group	Abundance (%) at site 1	2	3	4	5	6	7	8	9	10
					Main channel					
Oligochaeta	24·1	56·7	44·4	67·8	46·3	41·8	40·9	26·6	47·4	40·7
Crustacea	0·2	0·01	0·01	2·2	0·2	0·1	0·03	0	0·1	0
Plecoptera	0·1	0·1	0·02	0·04	0·04	0·5	0·03	0·04	0·3	0·1
Ephemeroptera	20·5	4·8	1·1	1·1	0·5	2·3	6·8	31·9	7·1	32·7
Trichoptera	2·7	0·4	0·5	6·3	27·6	29·8	11·1	14·7	2·6	0·6
Coleoptera	6·0	0·7	0·2	0·3	0·1	0·1	0·01	0·1	0·1	0·6
Diptera (Chironomidae)	40·5	29·9	50·5	21·1	23·7	24·6	39·0	18·7	31·1	17·8
Diptera (others)	2·4	4·7	2·0	0·1	0·04	0·5	0·8	0·6	0·3	0·3
Other insects	0·04	0·01	0·01	0·02	0	0·01	0·1	0·1	0·3	0·1
Hydracarina	3·4	2·7	1·2	0·04	0·1	0·03	0·2	0·3	0·2	0·03
Mollusca	0·02	0·03	0·03	1·0	1·4	0·3	1·1	6·8	10·7	6·7
Others	0·2	0·1	0	0·2	0·2	0·01	0·01	0·02	0·1	0·3
$10^{-3}\times$ Total catch	45·2	15·5	26·8	11·0	16·4	31·0	7·4	6·8	2·0	16·4
					Bank					
Oligochaeta	22·9	47·9	82·5	38·1	74·5	60·5	52·5	59·5	75·7	51·1
Crustacea	0·03	0·1	0·1	1·7	1·0	0·3	0·03	0·2	0·1	0·1
Plecoptera	0·3	0·6	0·2	0·04	0·01	0·04	0·2	0·2	0·1	0·9
Ephemeroptera	5·9	5·4	0·7	0·7	0·5	1·0	1·2	8·6	3·8	27·7
Trichoptera	3·6	1·0	0·4	11·6	6·3	10·8	2·9	11·0	1·4	0·5
Coleoptera	2·9	0·9	0·5	0·03	0·1	0·01	0·1	0·04	0·1	0·1
Diptera (Chironomidae)	55·6	40·0	14·4	44·7	15·3	26·5	42·2	16·5	16·8	11·4
Diptera (others)	7·2	3·1	0·4	0·1	0·1	0·3	0·2	0·2	0·3	0·2
Other insects	0·02	0·02	0·2	0·1	0·03	0·2	0·5	1·9	1·0	0·6
Hydracarina	1·4	1·0	0·1	0·04	0·1	0·03	0·03	0·04	0·03	0·2
Mollusca	0·2	0·1	0·2	2·8	1·5	0·3	0·2	1·7	0·5	0·6
Others	0·1	0·1	0·4	0·2	0·7	0·1	0·01	0·1	0·1	6·5
$10^{-3}\times$ Total catch	64·1	54·2	30·8	20·0	11·0	12·6	11·7	13·7	28·3	50·6

sites 1 and 2 as a group (subject to the fewest disturbances) had significantly higher numbers of taxa than sites 3–10 (as a group) both in the main channel ($t = 5{\cdot}96$, d.f. = 118, $P<0{\cdot}001$)

and at the bank ($t = 3 \cdot 84$, d.f. = 118, $P<0 \cdot 001$). Such t-tests applied to the mean densities (after transformation to $\log_{10}$) also showed significant differences between these groups of sites ($t = 3 \cdot 75$, $5 \cdot 19$, d.f. = 118, $P<0 \cdot 001$ for the main channel and bank, respectively).

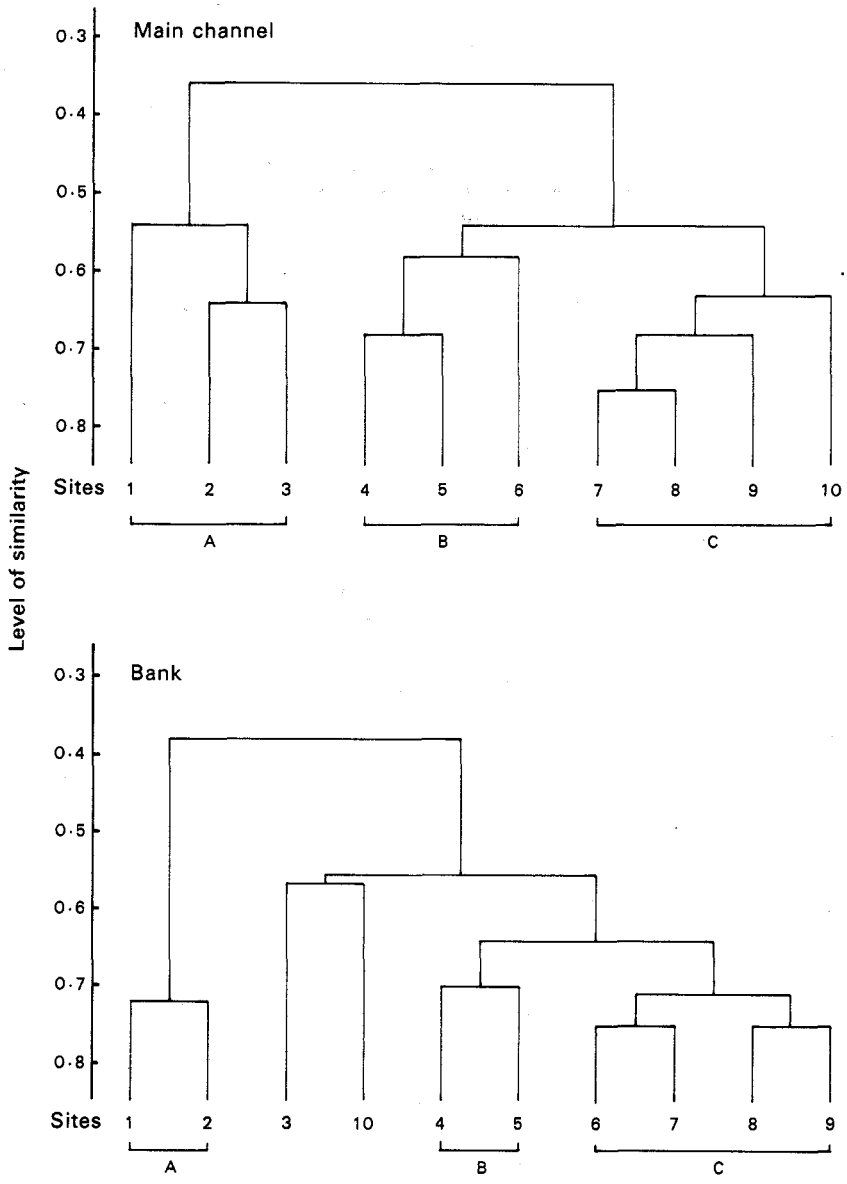

Fig. 2. Classification of the sites, based on Czekanowski's index. Site groups are bracketed together.

Within each group of sites, two-way ANOVAs indicated significant spatial and temporal variation in mean density or number of taxa (Table 3), except for bank samples at sites 1 and 2. Both density and number of taxa tended to decrease during winter and increase during spring and summer. The F_{max}-test (Sokal and Rohlf 1969) indicated that variances were homogeneous for each ANOVA except for number of taxa in the main channel at

sites 1 and 2; a *t*-test for unequal variances indicated that at least the spatial variation here was significant ($t = 3 \cdot 05$, d.f. = 22, $P < 0 \cdot 05$).

The percentage abundance of the major invertebrate groups did not vary markedly between sites or between habitats (Table 4). Oligochaeta and Chironomidae dominated most sites, each usually constituting more than 20% of all individuals collected from a site. Ephemeroptera and Trichoptera were common with a frequency of up to 30% at a few sites. All other groups constituted less than 10% of the total catch.

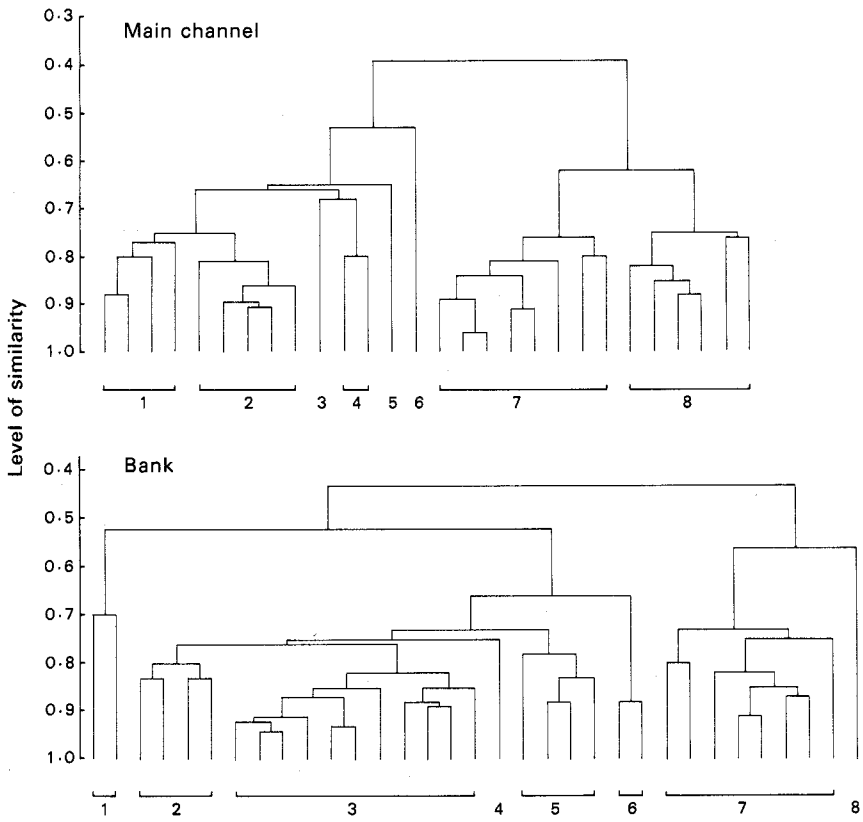

Fig. 3. Classification of the common taxa, based on Czekanowski's index. Taxa groups are bracketed together. Names of the taxa in each group are given in Table 5.

The common taxa (see Appendix) were defined as those representing more than 0·5% of the total number of individuals collected. Oligochaeta were excluded from this total as they were not identified to species. The 28 common taxa in the main channel and the 33 at the bank constituted 40–50% of the total numbers collected from both habitats and with the Oligochaeta constituted just over 90% of the fauna. The common taxa were distributed among most of the major invertebrate groups (Table 4) except the Crustacea and the Plecoptera, which were dominated by Atyidae and Gripopterygidae, respectively.

Grouping of the Sites

Dendrograms based on Czekanowski's index (Fig. 2) calculated for the combined data from all samples collected during the study indicate a distinct grouping of the sites. For samples from the main channel, the same site groups were also obtained with the Canberra Metric index; for bank samples, slightly different site groups were produced by this index.

Sites in the main channel were clearly divided into two groups at a similarity level of 0·50: the upstream sites (1, 2 and 3) and the downstream sites. At a higher similarity level (0·55), three groups were evident (A, B, and C, Fig. 2), although at this level of similarity site 1 was not quite a member of group A but was ungrouped. However, as site

Table 5. Total numbers of individuals in the common taxa at each site in the main channel (*a*) and at the bank (*b*)

Sites composing each site group are indicated. — No specimens caught

(*a*) Taxa group No.	Taxa in group[A]	Total number at each site									
		Site group A			Site group B			Site group C			
		1	2	3	4	5	6	7	8	9	10
1	*Corbiculina australis*	1	1	3	63	179	20	80	453	205	1083
	Tanytarsini sp. 122E	—	11	10	176	61	131	138	424	196	66
	Tasmanocoenis tonnoiri	52	7	78	43	37	400	419	2130	118	5288
	Ecnomus spp.	—	8	48	615	4159	7380	716	916	19	42
2	*Rheotanytarsus* sp. 1	15	6	263	125	135	763	80	20	6	136
	Cricotopus sp. 1	666	15	211	70	2706	2054	514	87	12	28
	?*Eukiefferiella* sp. 1	621	148	2316	405	467	1157	1087	318	61	833
	?*Calopsectra* sp. 1	1794	230	3565	202	83	83	319	149	22	154
	Polypedilum sp. 1	237	176	1567	66	36	244	237	24	60	879
3	nr *Saetheria* sp. 1*	90	546	3	—	—	2076	96	31	15	39
4	*Harnischia* gp sp. 2	16	21	172	16	—	9	34	32	1	317
	Empididae sp. 3*	118	9	424	2	3	115	57	38	1	46
5	*Cheumatopsyche* sp. 1*	13	1	17	—	284	1189	54	10	3	16
6	Orthocladiinae sp. 103E*	—	—	—	5	66	394	22	2	134	2
7	*Atalophlebioides* sp. 4*	2909	276	8	1	—	—	—	—	—	—
	Atalonella sp. 4	1505	29	11	1	—	1	—	—	—	—
	Cyphon sp. 1 (larvae)*	1857	31	5	—	—	1	—	—	—	—
	Dasyhelea sp. 1*	393	533	2	1	—	—	—	—	—	—
	Hydracarina sp. 21*	408	154	5	—	—	—	—	—	—	—
	Atalonella sp. 2	707	38	9	12	1	—	—	—	—	—
	Baetis sp. 4*	647	32	35	1	2	5	3	2	—	—
	Hydracarina sp. 17*	358	32	166	—	—	—	—	—	—	—
8	*Riethia* sp. 1	4583	114	61	311	36	37	16	3	3	5
	Thienemaniella sp. 1	626	110	242	52	86	147	—	—	1	2
	Pentaneura sp. 1	3253	132	35	58	26	23	2	1	—	1
	Leptophlebiidae immature	3067	339	123	29	20	5	—	2	—	2
	nr *Cordites* sp. 1	3872	1380	2527	3	5	38	25	3	2	1
	Corynoneura sp. 1*	1229	1045	386	20	3	—	—	—	1	1

[A] Asterisks indicate taxa that were common in one habitat only.

1 was clearly more similar to sites 2 and 3 than to any others, the three sites were accepted as a group. Classification procedures such as these are merely a tool to aid in the selection of groups from complex data sets.

Sites along the bank were divided at a similarity level of 0·50 into almost the same two distinct groups as in the main channel. At a higher similarity level (0·67), three distinct groups were formed (A, B, C, Fig. 2) and two sites (3, 10) were ungrouped. With the

Canberra Metric index, sites 5 and 6 and sites 7–9 formed groups but site 4 was ungrouped; the grouping of the other sites was unchanged. Even with this index, however, site 4 was more similar to sites 5 and 6 than to any others, but this was obscured by the clustering strategy. The groups based on Czekanowski's index were ultimately accepted as fewer sites remained ungrouped with this index.

Table 5 (contd)

(*b*) Taxa group No.	Taxa in group[A]	Total number at each site									
		Site group A			Site group B		Site group C				
		1	2	3	4	5	6	7	8	9	10
1	Turbellaria sp. LTCS1*	8	—	45	6	30	7	1	10	—	2910
	Parachironomus sp. 1*	—	—	1	17	18	62	—	4	16	2681
2	*Corbiculina australis*	110	21	4	551	154	32	19	207	125	245
	Tasmanocoenis tonnoiri	397	17	12	43	36	103	115	1022	118	12 350
	Ecnomus spp.	11	5	40	2251	658	1281	283	1402	331	88
	Tanytarsini sp. 122E	—	15	3	2139	29	193	43	401	562	49
3	*Rheotanytarsus* sp. 1	219	6210	89	846	69	288	19	90	106	380
	Cricotopus sp. 1	989	336	92	1893	377	475	122	82	331	139
	?*Eukiefferiella* sp. 1	849	506	130	902	181	239	220	179	196	1199
	*Cryptochironomus grisiedorsum**	57	391	146	596	162	156	105	97	106	20
	Polypedilum sp. 1	6883	4314	1442	234	274	615	1688	459	813	159
	?*Calopsectra* sp. 1	11 993	4590	411	489	159	268	173	125	184	53
	Procladius sp. 1*	727	70	154	39	33	105	147	27	170	21
	Riethia sp. 1	2216	264	43	581	88	113	20	46	23	10
	Thienemaniella sp. 1	900	1627	80	98	25	42	27	5	24	8
	Harnischia gp sp. 2	1277	1009	101	228	7	34	34	40	42	194
	Pentaneura sp. 1	1785	488	40	376	39	22	3	3	5	48
4	*Psectrocladius* sp. 1*	26	94	15	37	17	42	47	20	6	579
5	Corixidae immature*	6	—	34	14	2	28	55	242	266	224
	Chironomus sp. 4*	20	78	1035	15	33	213	209	87	640	16
	?*Microchironomus* sp. 1*	11	2	342	21	17	84	113	110	258	6
	Polypedilum sp. 6*	3	27	43	8	14	87	1939	427	1037	14
6	*Baetis* sp. 5*	20	89	1	2	—	7	6	92	90	763
	Baetidae immature*	107	151	9	6	1	9	6	58	141	859
7	*Atalonella* sp. 2	1098	1138	10	15	—	—	—	—	21	3
	Leptophlebiidae immature	570	307	30	49	4	5	3	—	20	29
	Atalonella sp. 4	498	208	2	1	—	—	7	—	—	—
	Austrolimnius sp. L25E*	911	240	50	—	2	—	—	1	3	2
	Ceratopogonidae sp. 15*	1219	306	14	—	1	1	1	—	4	3
	Stempellina nr *bausei* sp. 1*	3975	162	13	—	1	—	1	1	1	1
	Nilobezzia sp. 1*	2044	162	14	—	1	4	—	—	2	1
	nr *Cordites* sp. 1	3872	6210	105	7	—	3	6	—	1	—
8	?*Ecnomina* sp. 1*	785	4	—	—	—	—	—	1	—	—

[A] Asterisks indicate taxa that were common in one habitat only.

Grouping of the Taxa

Excluding the Oligochaeta, the grouping of the common taxa with Czekanowski's index was distinct (Fig. 3). Seven groups were evident for samples from the main channel at a similarity level of 0·70. At a slightly higher level of similarity (0·76), the first group could

be split into two (groups 1 and 2). The distribution among the sites of the total number of each common taxon (Table 5) shows that the taxa in group 1 were less abundant at sites 1–3 compared with downstream sites than those in group 2. Thus, this additional division seems justified. For bank samples, five groups of taxa were clear at a similarity level of 0·70. The second group was much larger than the others and at a higher level of similarity (0·77) could be split into four groups (taxa groups 2, 3, 4, 5), which, as before, on the basis of total numbers (Table 5) appeared justified. Therefore, eight groups of taxa were finally recognized for each habitat.

These groups of taxa displayed three basic patterns of distribution (Table 5): groups of taxa that were abundant at all sites (groups 2 and 4, main channel; group 3, bank); groups of taxa that reached their highest abundances at the first few sites (groups 7 and 8, main channel and bank); and groups of taxa that were most common at sites 3–10 (group 1, main channel; groups 2 and 5, bank). The remaining groups of taxa consisted of a single taxon or pairs of taxa that were generally abundant only at site 10 (groups 1 and 4, bank) or group B sites (groups 3, 5 and 6, main channel).

Table 6. Classification of cases by the discriminant analysis for site groups from the main channel (*a*) and the bank (*b*)

(*a*)

Initial site group	Percentage correct	Number of cases classified into site group A	B	C
A	100·0	27	0	0
B	96·4	0	27	1
C	88·4	1	4	38
Total	93·9	28	31	39

(*b*)

Initial site group	Percentage correct	Number of cases classified into site group A	Site 3	B	C	Site 10
A	100·0	21	0	0	0	0
Site 3	83·3	0	5	1	0	0
B	89·5	1	0	17	1	0
C	70·7	0	0	7	29	5
Site 10	63·6	0	0	0	4	7
Total	80·6	22	5	25	34	12

The Canberra Metric index produced more or less the same groups of taxa. In the main channel, 24 of the 28 common taxa were placed in the same groups as those obtained with Czekanowski's index; at the bank, 22 of the 33 common taxa remained in the same groups. As noted below in the Discussion, some of the taxa at the bank (in group 3) were misclassified with Czekanowski's index; when they were moved to the appropriate group only 7 of the 33 taxa had a different classification with the Canberra Metric index. Thus, the taxa groups recognized above could be considered as robust.

Multivariate Analysis

There were 98 cases (or sets of readings) with complete data for the water quality variables. This is fewer than the maximum of 120 cases (12 visits × 10 sites) because there were missing data. Two discriminant analyses were performed, one with the cases pregrouped according to site groups in the main channel (A, B, C; Fig. 2) and the other with the cases pregrouped according to the site groups at the bank (A, site 3, B, C, site 10; Fig. 2). For the main channel, there was a high level of agreement between the chemical and biological classifications of the sites (Table 6), indicating that these site groups were

well discriminated by the chemical variables. The bank groups (Table 6) showed a similar high level of agreement for group A, site 3 and group B, but a lower level of agreement for group C and site 10; these last two were not well discriminated from each other. When the measurements for the variables (except pH) were log-transformed before the analyses, the discrimination of group C (in both habitats) was improved but that of the other groups was hardly altered.

Table 7. Coefficients for the discriminant functions and the correlation coefficients (*r*, in parentheses) of the variables with the discriminant scores in the main channel (*a*) and at the bank (*b*)

Number beside each variable indicates the order in which they were entered into the discriminant analysis. Percentage of the total variation accounted for by each discriminant function is given. For 96 degrees of freedom, the critical *r* values are 0·21 ($P<0·05$) and 0·27 ($P<0·01$)

(*a*)

Variable	Coefficient for discriminant function	
	I (70%)	II (30%)
pH (3)	−2·79 (−0·58)	−1·32 (−0·08)
Temperature (9)	−0·02 (−0·30)	−0·12 (−0·29)
Suspended solids (4)	0·02 (−0·42)	0·04 (0·42)
Turbidity (2)	−0·08 (−0·46)	−0·09 (0·13)
K_{20} (1)	−0·08 (−0·82)	−0·01 (0·39)
Total Kjeldahl nitrogen (6)	−0·79 (−0·14)	−1·06 (−0·20)
Filterable reactive phosphorus (5)	12·12 (0·18)	2·36 (0·01)
K^+ (7)	0·21 (−0·72)	1·66 (0·48)
Mg^{2+} (8)	−0·01 (−0·48)	−0·14 (−0·12)
Constant	22·90	9·61

(*b*)

Variable	Coefficient for discriminant function			
	I (57%)	II (28%)	III (12%)	IV (3%)
pH (5)	−2·95 (−0·57)	0·65 (0·16)	1·42 (0·01)	−2·95 (−0·19)
Suspended solids (3)	0·02 (−0·43)	−0·01 (0·01)	−0·06 (−0·66)	−0·02 (−0·28)
Turbidity (4)	−0·08 (−0·47)	0·02 (−0·08)	0·09 (−0·18)	−0·001 (−0·18)
K_{20} (1)	−0·07 (−0·85)	−0·01 (−0·01)	−0·02 (−0·30)	0·10 (0·40)
Total Kjeldahl nitrogen (6)	−0·96 (−0·21)	−0·45 (−0·30)	0·62 (0·23)	−1·04 (−0·19)
Filterable reactive phosphorus (2)	2·22 (−0·04)	−35·86 (−0·97)	−3·83 (0·04)	−1·23 (−0·07)
Constant	24·39	−3·17	−9·58	20·48

The coefficients of the discriminant functions for the two analyses are given in Table 7. The variables in each equation are those that provided any significant ($P<0·05$) discrimination between the site groups. For the main channel site groups, significant separation ($P<0·05$) occurred after entry of the first variable, but for the bank site groups this occurred only after the entry of the first three variables. In order to facilitate interpretation, correlation coefficients between the scores of the discriminant functions and the readings for each of the discriminating variables were calculated (Table 7).

For the main channel, most separation of site groups occurred with the first discriminant function, which accounted for 70% of the variation in the water quality data and was most highly correlated ($r = 0·82$, $P<0·01$) with conductivity (K_{20}). The second function accounted for the remaining variation and appeared to be responding ($r = 0·42$, $P<0·01$)

to changes in suspended solids (SS) as well as in K_{20} and K^+ ($r = 0{\cdot}39$, $0{\cdot}48$, $P<0{\cdot}01$). Thus, site groups A, B and C (main channel) could be discriminated from each other (on the basis of water quality) mostly by changes in K_{20}, which steadily increased from sites 1 to 10 (Table 1). Group B could be further discriminated from groups A and C by a combination of differences in the levels of SS (lowest at B) and K_{20} and K^+ (highest at C).

When the analysis was based on the site groups at the bank, the first discriminant function accounted for 57% of the total variation in the water quality data and was again most highly correlated ($r = 0{\cdot}85$, $P<0{\cdot}01$) with K_{20}. The second function was quite clearly responding ($r = 0{\cdot}97$, $P<0{\cdot}01$) to changes in the concentration of filterable reactive phosphorus (FRP). The third was mostly related to the levels of SS ($r = 0{\cdot}66$, $P<0{\cdot}01$). The fourth function provided little discrimination as it accounted for only 3% of the total variation. Thus, the five site groups at the bank were also distinguished from each other by changes in K_{20}. In addition, high levels of FRP clearly separated site 3 from the other groups, and SS further separated group B sites (with low values for this variable) and site 10 (with high values). For both habitats, the same factors emerged when log-transformed data were used.

The principal components analysis gave similar conclusions. The first four principal components explained 75% of the variability in the water quality data, the first one 43%. The first component was mostly related to changes in total dissolved solids (TDS), K_{20} and ionic concentrations. The second component (16% of variation) was associated with turbidity and SS, whereas the third (9% of the variation) and fourth (6% of the variation) components reflected changes in FRP, total phosphorus (TP) and total Kjeldahl nitrogen (TKN). When the analysis was done with log-transformed data, the same factors emerged.

The ranking of the factors from both multivariate analyses is naturally specific only to the 10 sites used. If another 10 had been selected with more sites in the impounded sections or above any obvious disturbances, i.e. above site 3, then a different ranking of the factors, if not different factors, would have emerged.

Discussion

Site Groups

The disturbances of the river due to industrial development are, in order downstream of sites 1 and 2, the discharge of treated sewage, the damming of the river, the discharge of heated water, and the discharge of saline waste water. It is now possible to relate these disturbances to variations in the distribution of the fauna as shown by the site groups.

For both the main channel and the banks, sites 1 and 2 were clearly distinguished from downstream sites by their faunal composition (Fig. 2) and chemical features (Table 6). The bank fauna at these sites was distinctly richer in taxa and density of individuals than downstream sites (Table 2). More or less the same occurred with the main channel fauna, although site 2 was not as distinct from sites farther downstream as site 1. In both habitats, sites 1 and 2 were placed in site group A (Fig. 2), which the discriminant analysis showed was most distinguished from other site groups by low readings for K_{20} (Table 1); measurements of correlated variables such as TDS ($r = 0{\cdot}9$, $P<0{\cdot}01$) and the major ions ($r = 0{\cdot}5$–$0{\cdot}8$, $P<0{\cdot}01$) were also low at these sites. On the basis of these results it is reasonable to conclude that sites 1 and 2 were the least disturbed, suggesting that current agricultural practices at these two sites were less disruptive than the combined effects of industrial development and agriculture at downstream sites.

The main channel fauna at site 3 was also placed in site group A, but the bank fauna was ungrouped (Fig. 2). The flow from the Moe Drain, which enters just upstream of site 3 (Fig. 1) carrying treated sewage, does not mix with the main flow of the La Trobe River until downstream of this site (B. Harasymiw, personal communication). Therefore, the

bank fauna at site 3 was subjected to organically polluted water, thus accounting for its lack of similarity with the fauna of sites 1 and 2, whereas the main channel fauna largely escaped this pollution and remained similar to the fauna upstream. The discriminant analysis supports this explanation by showing that high FRP levels (Table 1), which generally indicate organic pollution (Mason 1981), clearly characterized site 3 at the bank. As water samples for chemical analysis were taken only near the bank, the values for site 3 cannot be considered as representative of conditions in the main channel if, as there seems, there were persistent differences in water chemistry between the two habitats. The values for the variables usually associated with organic pollution, e.g. O_2, NH_4-N, TKN, FRP (Table 1), indicated that such pollution was confined to site 3.

Sites 4 and 5 were both on impounded sections of the river and had significantly lower water velocities than in the main channel (see above). In addition, site 5 was immediately downstream of the point where heated water was discharged. However, because the faunal composition of the two sites was similar (both were in group B in both habitats, Fig. 2), it seems that slow flow rather than heated water had most influence on the fauna. The Narracan Dam had little or no influence on water temperature at site 4 (Table 1) because water was retained for only several days (B. Harasymiw, personal communication). Before 1976, water temperatures reached a maximum of 35°C 1 km downstream of site 5; since then effluent temperatures have been lowered and river temperatures have not exceeded 25–26°C at site 5 (Table 1; B. Harasymiw, personal communication). Blyth (1979) in February 1974 found only seven taxa in 0·8 m^2 at site 5 whereas in this study a minimum of 13 in 0·6 m^2 and usually 20–30 during summer were recorded. Others (Coutant 1962; Mann 1965) have also reported that reductions in benthic fauna in rivers occur at temperatures greater than 30°C but that there appears to be little impact below this temperature.

The discriminant analysis demonstrated that group B sites could be distinguished from other groups by their lower concentrations of SS (Table 1), which may well have resulted from lower water velocities. However, at site 6, which was located in group B for samples from the main channel and which had low SS values (Table 1), water velocities were not significantly lower than at other sites. Thus, low concentrations of SS were not necessarily associated with low water velocities. The presence of logs in the main channel at site 6 may have had some influence on the fauna but not in any obvious manner.

Samples from the bank at site 6 were grouped with those from sites 7–9. Sites 7–9 were usually the most depauperate sites (Table 2) and consistently formed a group (C) in both habitats. The discriminant analysis indicated that group C sites were best distinguished from others by their high readings for K_{20} (Table 1); the concentrations of such correlated variables as TDS and the major ions were also high at these sites (Table 1). The Morwell River, which enters the La Trobe River upstream of site 7, has elevated TDS levels compared with the La Trobe River upstream of site 3 and receives saline waste water from the SECV's activities. Between July 1979 and July 1981, the mean value for TDS in the Morwell River below the principal point of release of saline water was 480 mg l^{-1} (range 241–750) and above this point 197 mg l^{-1} (159–290) (B. Harasymiw, personal communication). Discharges from the APM pulpmill (between sites 7 and 8) appeared to have little additional impact on water quality. Site 6 also received some saline wastes, from the Blue Lagoon, but these flowed along the southern bank, where the bank samples at site 6 were taken, without mixing much with the main flow of the river (B. Harasymiw, personal communication). This may account for the affinity of the bank fauna at this site with that at sites 7–9. It should be remembered that there was some discrepancy between the two similarity indices in the classification of the bank fauna at site 6.

In the main channel, site 10 was also grouped with sites 7–9 (Fig. 2), although at the bank it was ungrouped. The fauna at this site was richer than the fauna at sites 7–9 (Table 2), suggesting that there was less impact at site 10, especially at the bank, of the various effluents discharged upstream. The discriminant analysis indicated that the bank

at site 10 was distinguished from sites in group C by high values for SS, but the discrimination of these groups was relatively poor (Table 6) and no obvious biological interpretation can be placed on it.

As the fauna was relatively impoverished at sites 7–9, it is tempting to attribute this directly to the higher K_{20} and generally increased load of dissolved material at these sites. Such values (Table 1) have not previously been reported as directly toxic to benthic invertebrates (Hynes 1970) and they were still high at site 10 where there appeared to be less impact on the fauna. If high conductivity and high levels of dissolved solids had an effect on the fauna, it was probably indirect: for example, such levels may have diminished or altered food supply to the fauna. It is also possible that other unmeasured toxic chemicals had an effect at these sites. Perhaps the higher concentrations of dissolved material downstream of the junction of the two rivers must simply be accepted as a rough indication of the generally lowered water quality at these sites, of which some unknown feature is responsible for the lower species richness and abundance. This shows that multivariate analyses for interpreting biological differences are only as useful as the data entered into them.

Sediment characteristics were not entered as part of the multivariate analyses because they were not related to the faunal changes in either habitat. There was no significant ($P<0{\cdot}05$) variation in the organic content of the substratum between sites, and, although there was significant variation in grain size, the differences between sites did not correspond with differences in the fauna. In both habitats, mean grain size at site 1 was significantly larger than that at sites 2 or 3, yet the fauna at these sites was most similar to that at site 1. At the more downstream sites, there were only a few significant differences in grain size and these also did not correspond with faunal differences.

In contrast, the consistent differences between the main channel and the bank in both the sediment characteristics and in water velocity were probably related directly or indirectly to the differences in the fauna between these two habitats: in addition to the 27 taxa common ($>0{\cdot}5\%$) in only one habitat (Table 5), there were 34 other taxa unique to the main channel and 80 unique to the bank (Marchant *et al.* 1984).

Taxa Groups

As shown in Table 5, the groups of taxa displayed three basic patterns of distribution. Group 2 in the main channel and group 3 at the bank contained taxa that were abundant at all sites; these taxa, five of which were the same in both habitats, were presumably not affected by the various disturbances downstream of sites 1 and 2 and were considered resistant taxa. On the other hand, groups 7 and 8 at the bank and main channel consisted of taxa, of which four were the same in both habitats, that were clearly most abundant at the least disturbed sites 1 and 2 and were thus considered sensitive taxa. Finally, group 1 of the main channel and group 2 at the bank comprised the same four taxa, which, together with those in group 5 at the bank, were chiefly abundant at the disturbed sites. Either these taxa have adapted well to the various disturbances and could be considered opportunistic or their distribution reflects longitudinal variation in the fauna that existed before any disturbance occurred.

All the resistant taxa in both habitats were Chironomidae and except for three (*C. grisiedorsum*, *Procladius* sp. 1, *Harnischia* gp sp. 2) they were also abundant and widespread in the fairly undisturbed upper catchment of the La Trobe River (Metzeling *et al.* 1984). Three of the resistant taxa at the bank (*Riethia* sp. 1, *Thienemaniella* sp. 1, *Pentaneura* sp. 1), which tended to decrease in abundance at the lower sites, were classified as sensitive taxa (group 8) in the main channel and are probably best considered as sensitive in both habitats. Thus, the Chironomidae in the La Trobe River are not generally resistant to changes in water quality. The two dipteran taxa in group 4 of the main channel could

also be classified as resistant, although they were absent or rare at a few of the disturbed sites; both occurred throughout the upper catchment. The Oligochaeta as a group, although not included in the inverse analysis, could be classified as resistant.

The sensitive taxa were more diverse (see Appendix). In addition to the previous three chironomids, three other sensitive taxa including two mayflies, *Atalonella* sp. 2, Leptophlebiidae immature, and nr *Cordites* sp. 1, were also widespread and abundant in the upper catchment. These six taxa all tended to be distributed in greater numbers downstream of the undisturbed sites, probably indicating that they were more tolerant than others in these groups. The other sensitive taxa were also recorded in the upper catchment, but they were not as widespread or as abundant. Of the uncommon taxa, not included in the inverse classification, 19 species of Ephemeroptera (13 of Leptophlebiidae, 4 of Baetidae, 2 of Siphlonuridae), 15 species of Plecoptera (1 of Eusthenidae, 1 of Notonemouridae, 3 of Austroperlidae, 10 of Gripopterygidae), and 59 species of Trichoptera were usually found only at the first three sites (Marchant *et al.* 1984) and could all be considered as sensitive taxa. Plecoptera and Ephemeroptera have often been shown to be sensitive to various disturbances of rivers (Hynes 1960; Mason 1981). For instance, in Tasmania, Norris *et al.* (1982) have already shown that leptophlebiid mayflies are sensitive to river pollution by heavy metals; a species of baetid, *Baetis baddamsae*, was resistant to such pollution.

The two mayflies (both baetids) in group 6 of the bank could also be considered as sensitive, but, in addition, they showed an increase in abundance at the lowest sites (8–10) indicating some ability to recolonize disturbed sites. Two species of uncommon Gripopterygidae, *Leptoperla neboissi* McLellan and *L. primitiva* McLellan, had similar distributions.

The seemingly opportunistic taxa, *C. australis*, *Ecnomus* spp., *T. tonnoiri*, were also found in the upper catchment and tributaries of the La Trobe River (Metzeling *et al.* 1984), but were only abundant at lowland sites on the Tyers and Morwell Rivers (Fig. 1). Thus the three taxa could be classed as lowland species. As sites 1–10 are all lowland sites, the increase in abundance of the three taxa downstream of the undisturbed sites suggests that these taxa are, indeed, opportunistic. For instance, *Ecnomus* spp. were generally most abundant at sites 4–6; *Cheumatopsyche* sp. 1 in taxa group 5 of the main channel, was also abundant at sites 5 and 6. As these two taxa feed on plankton as well as on benthic organisms (Chessman 1982), it is not surprising that they had high abundances downstream of impounded sites where plankton would be abundant. *Paratya australiensis* (Kemp), although not included with the common taxa, was also numerous at sites 4 and 5 only. According to Williams (1977), this species prefers areas in rivers with reduced current, the factor that characterized these sites.

Of the other opportunistic taxa, a species of *Chironomus* in taxa group 5 at the bank was very abundant at site 3, which was exposed to organically polluted water. This genus has long been known as an indicator of such pollution (Mason 1981). Another chironomid in this taxa group, *Microchironomus* sp. 1, was also abundant at this site. Neither of these species occurred in the upper catchment.

General Features

There are few other studies of disturbed rivers in temperate Australia, especially of those affected by industrial or urban areas, with which the results of this study can be compared. Jolly and Chapman (1966) and Campbell (1978) studied streams receiving largely domestic organic pollution. They were able to show clearly a reduction in fauna below the input of pollutants, but their analyses were based on a lower level of taxonomic discrimination than achieved in this study and comparisons of faunal richness are not possible. Arthington *et al.* (1982), who studied the effects of organic pollution on an urban stream in Brisbane, identified 240 taxa from 12 sets of samples taken at eight sites over

a year. This number is comparable with that in this work, although they took fewer samples per site and identified Oligochaeta (five species).

As already mentioned, the density of individuals and the total number of taxa tended to decrease in both habitats during winter and increase during spring and summer. These trends were clearer for densities than for number of taxa and for dominant groups such as Oligochaeta and Chironomidae. The variations in density were in broad agreement with Hynes' (1970) scheme for seasonal fluctuations in abundance of aquatic insects in temperate (Northern Hemisphere) streams. In this scheme, a major peak in abundance occurs in autumn or winter due to recruitment from eggs laid in summer, and a variable peak in summer due to recruitment of fast-growing summer species. At sites 1–10 there was generally only one peak, which occurred in summer or early autumn, whereas in the upper catchment the peak occurred in winter (Metzeling *et al.* 1984). Details of the seasonal fluctuations in abundance of some of the common taxa will be included elsewhere in studies of life histories.

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Appendix. Systematic list of the common taxa collected at the bank and in the main channel at sites 1–10

Nomenclature is that used in the voucher collection of the Biological Survey Department of the Museum of Victoria

Class or order	Family	Taxon
Turbellaria		Turbellaria sp. LTCSI
Bivalvia	Corbiculidae	*Corbiculina australis* (Deshayes)
Acarina	Hydracarina	Hydracarina sp. 17
		Hydracarina sp. 21
Ephemeroptera	Baetidae	*Baetis* sp. 4
		Baetis sp. 5
		Baetidae immature
	Caenidae	*Tasmanocoenis tonnoiri* Lestage
	Leptophlebiidae	*Atalophlebioides* sp. 4
		Atalonella sp. 2
		Atalonella sp. 4
		Leptophlebiidae immature
Hemiptera	Corixidae	Corixidae immature
Coleoptera	Helminthidae	*Austrolimnius* sp. L25E (larvae)
	Helodidae	*Cyphon* sp. 1 (larvae)
Diptera	Chironomidae (Orthocladiinae)	*Cricotopus* sp. 1
		?*Eukiefferiella* sp. 1
		Corynoneura sp. 1
		nr *Cordites* sp. 1
		Psectrocladius sp. 1
		Thienemaniella sp. 1
		Orthocladiinae sp. 103E
	Chironomidae (Chironominae)	*Riethia* sp. 1
		Cryptochironomus grisiedorsum (Kieffer)
		nr *Saetheria* sp. 1
		Polypedilum sp. 1
		Polypedilum sp. 6
		Harnischia gp sp. 2
		Chironomus sp. 4
		Parachironomus sp. 1
		?*Microchironomus* sp. 1
		Rheotanytarsus sp. 1
		?*Calopsectra* sp. 1
		Stempellina nr *bausei* sp. 1
		Tanytarsini sp. 122E
	Chironomidae (Tanypodinae)	*Pentaneura* sp. 1
		Procladius sp. 1
	Empididae	Empididae sp. 3
	Ceratopogonidae	*Dasyhelea* sp. 1
		Nilobezzia sp. 1
		Ceratopogonidae sp. 15
Trichoptera	Ecnomidae	?*Ecnomina* sp. 1
		Ecnomus spp.
	Hydropsychidae	*Cheumatopsyche* sp. 1